SELECTION OF HIGH-TEMPERATURE BINDER PG GRADES FOR AIRFIELD PAVEMENTS

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ABSTRACT

Most highway departments in the United States and Canada have over the past 10 years adopted performance-graded (PG) binders for use in constructing hot mix asphalt pavements, forcing airfield pavement construction practice to adopt this approach to grading asphalts. The purpose of this study was to develop an effective and efficient system for selecting PG binders for use in airfield pavements. This required consideration of many factors and conditions that are substantially different from those encountered in highway pavements, the most important of these being tire pressure and aircraft/vehicle wander. The high tire pressures used in many aircraft landing gear will cause a significant increase in rutting rate compared to that caused by truck traffic, requiring a higher PG binder grade at a given traffic level. The procedure developed for selecting high-temperature PG grades used the newly developed LTPPBind Version 3.1 software, in combination with the rutting model developed for use in the 2001 Pavement Design Guide. The rutting model was used to develop a relationship between tire pressure and rutting damage that can then be used to adjust the base high-temperature PG grade recommended in the LTPPBind software. Traffic wander is considered in the system through pass-to-coverage ratios. Using this approach, a simple system has been developed for determining the required high-temperature PG grade for a given runway/taxiway as a function of design aircraft weight and average annual departures. The proposed system has been evaluated and refined through comparison with both current practice and performance records at a number of existing airfields. Although there is both practical and theoretical evidence suggesting that HMA pavements at airfields may be somewhat more prone to low-temperature cracking compared to highway pavements, it was determined that the most efficient means of addressing this performance issue was through adjustments in the HMA mix design.

INTRODUCTION

The purpose of this paper is to describe a system for selecting high-temperature PG grades for hot mix asphalt (HMA) used in airfield pavements. The PG binder grading system was originally developed for use in highway pavements, and has been successfully implemented throughout North America. It was meant as a more rational and efficient system for specifying asphalt binders, compared to the older viscosity grading system it replaced. At this time, few if any viscosity graded binders are marketed in North America, virtually all state highway agencies having adopted the PG system. This means that the PG system must now be fully adopted for use in airfield pavements. However, the PG grading system cannot be used directly for binder selection for airfield pavements, because of many important differences between aircraft loading of HMA pavements and truck loading of highway pavements. This paper describes a system for using the existing PG binder grading system for the selection of high-temperature binder grades for airfield pavements that accounts for the most important differences between the two types of loading.

The paper is organized into six sections: Acknowledgments; Performance Grading System for Asphalt Binders for Roadways; Selecting Binder PG Grades for Roadway Pavements; Current Binder Grade Selection Procedures for Airfield Pavements; Approach to Selection of High-Temperature PG Grades for Airfield Pavements; Development of Tire Pressure Factor; Grade Adjustments for Traffic Level and Speed; Recommendations; and References. The results of this research are currently being verified through laboratory testing and by comparison with grade selection in existing airfield pavements, and should therefore be considered preliminary.

PERFORMANCE GRADING SYSTEM FOR ASPHALT BINDERS FOR ROADWAYS

The primary objective of asphalt binder performance grading is to address three pavement distress modes: (1) permanent deformation or rutting at high pavement temperatures, (2) traffic-associated fatigue cracking at intermediate pavement temperatures, and (3) low-temperature cracking, due to thermal stresses in the pavement during rapid drops in temperature during the winter months. To address these three distress modes, the PG grading system provides for specifying the properties of binders at the high, intermediate and low pavement temperatures expected at the selected site. The PG grading system also includes high-temperature viscosity tests designed to ensure that the binder can be easily pumped throughout a typical hot-mix plant.

Three testing devices constitute the core of the PG grading system: the dynamic shear rheometer (DSR), the bending beam rheometer (BBR) and the direct tension tester (DTT). The DSR is used to characterize the binder at high and intermediate pavement temperatures. The BBR is used to measure the properties at expected minimum pavement temperatures. The limits that the asphalt binder properties must satisfy do not vary with climate; instead the temperatures at which those properties are measured vary. For example, the minimum pavement temperature is much lower in Minnesota than in Florida. The temperature at which the BBR test is carried out varies accordingly.

The tests that complete the Superpave system are laboratory aging procedures, which include the rolling thin film oven test (RTFOT) and the pressure-aging vessel (PAV). The RTOFT simulates the aging during production and construction, whereas the PAV is designed to simulate the aging during the first few years of service life of the pavement. It is important that some degree of binder hardening occurs during construction, so that the pavement is not tender and subject to excessive rutting. On the other hand, too much age hardening can render a pavement brittle and prone to fatigue cracking and related forms of distress. The viscosity of the asphalt binder at mixing and compaction temperatures is measured using the rotational viscometer (RV).

Current Standards

The current standards for the selection of PG graded asphalt binders are given in *AASHTO M320-05 Performance Graded Asphalt Binder*. In this specification, test results are specified on the unaged binder, the RTFOT residue and the PAV residue. The RTFOT (AASHTO T 240) is carried out for 75 minutes at 165ºC. After RTFOT aging, the binder is placed in the PAV (R 28) for aging at 100ºC for 20 hours.

Two rheological properties are controlled with the DSR: the complex modulus $|G^*|$ and the phase angle δ. The specified parameter at high temperatures—sometimes called the “rutting” parameter—is $|G^*|/\sin\delta$. Minimum values for this parameter help ensure that the binder is not too soft at expected maximum pavement temperatures. The limits are 1.0 kPa for the original binder and 2.2 kPa for RTFOT residue. In this, the high-temperature portion of the PG grading system the temperature at which $|G^*|$ and δ are measured is defined as the yearly 7 day average maximum pavement temperature at the location where the pavement is to be constructed; the testing frequency is 10 rad/s. The first number in the PG grading system refers to this critical temperature, and can be thought of as a maximum service temperature for that binder. For example, a PG 64-22 can be used up to a critical pavement temperature of 64°C, as defined by the 7-day average maximum pavement temperature. Although not addressed in detail in this paper, it should be noted that the second number in the PG system refers in a similar way to the minimum service temperature for the binder; a PG 64-22 can be used down to a minimum pavement temperature of –22°C. The PG 64-22 binder is probably the most commonly specified binder in the U. S. PG 58-28 binders are widely used in colder climates for lightly trafficked roadways. Stiffer binders, for example PG 70-22 and 76-22, are used in warmer climates and/or where traffic is very heavy and slow, such as interstate highways near major cities. Binders intended for such severe applications are often polymer modified, that is, they contain small amounts of polymer such as styrene-butadiene-styrene (SBS) or styrene-butadiene rubber (SBR). Although the PG grading system was developed in part to properly measure and specify the performance of such materials, there is increasing evidence that many polymer-modified binders exhibit significantly better performance than comparable non-modified binders. For this reason, their use should be seriously considered in where traffic is very heavy and/or slow, or where the application is of critical importance—for instance, in major urban highways where lane closures for maintenance and reconstruction should be avoided.

Traffic Speed and Volume

Extreme traffic conditions like high traffic volume and slow speeds are likely to generate early distresses in the HMA pavement, especially rutting. Asphalt is a viscoelastic material, which means that the physical response depends on both temperature and time of loading. Slow moving loads generate more permanent deformation than fast moving loads; stationary loads are even more damaging to HMA pavements. When high traffic volume or slow traffic is expected, the PG grade of the selected binder needs to be adjusted by increasing the high temperature portion of the PG grade. This is often referred to as grade "bumping." AASHTO M 320-05 includes a fairly simply scheme for grade adjustments, that includes adjustments of 0, 1 or 2 grades. These adjustments are based on engineering experience and judgment, and unfortunately no analysis supporting their use is given in AASHTO M 320 or any other reports or research papers. As a result, there are at least three other sets of recommended high-temperature PG grade adjustments. This includes grade adjustments as given in LTPPBind Versions 2.1 and 3.1, and grade adjustments recommended in the NCHRP Project 9-33 Interim Report (*3, 4, 5*). The computer program LTPPBind was developed by the Federal Highway Administration (FHWA) as an aid in PG grade selection, and is discussed in the section below.

SELECTING BINDER PG GRADES FOR ROADWAY PAVEMENTS

LTPPBIND Computer Program

LTPPBind, Version 2.1 was developed in 1999 by Pavement Systems, LLC for the FHWA. The program was designed to assist pavement engineers in selecting PG binder grades for use in the Superpave system of mix design and analysis (*1*). Some minor modifications to the Superpave system were included in version 2.1 of LTPPBind. LTPPBind 2.1 includes a very large database of climatic data for thousands of locations across the U. S. and Canada. This climatic data is then used in algorithms developed during SHRP to calculate both high- and low-temperature PG grades. The software includes provisions for calculating PG grades at different pavement depths, for estimating the reliability of different PG grades for a given application, and for making appropriate grade adjustments for traffic level and speed, as discussed in the previous section of this paper.

Recently, a newer version of LTPPBind has been developed—LTPPBind 3.1—that uses a more theoretically sound, damage-based procedure to estimate high temperature PG-grades (*2, 3*). Version 3.1 also uses more accurate methods for estimating pavement temperatures from climate data. The damage calculations in LTPPBind 3.1 are based upon the rutting model including the recently develop Mechanistic Empirical Design Guide for Flexible Pavements (MEDG) (*4*). LTPPBind 3.1 appears to provide similar high temperature grades in the 52 to 58°C range, but deviates at higher and lower grades. The discrepancy is particular large in hot desert climates, where extended periods of hot weather result in significantly higher PG grades using the damage-based approach (*3*). Analysis of LTPPBind 3.1 as part of AAPTP Project 4-2, and also as part of NCHRP Project 9-33, have indicated that it provides reasonably accurate base PG grades for highway pavements, and is to be preferred over earlier versions because of better accuracy and consistency with the MEDG (*4*). Therefore, base high-temperature PG grades as determined using LTPPBind 3.1 will be used in the system presented here for determining PG grades for airfield pavements. It should however be noted that because many highway engineers felt that LTPPBind 2.1 did not always provide reasonable grades, most state highway agencies have developed there own protocol for PG grade selection. Furthermore, as discussed below, the range of PG grades available in a given region tends to be limited, and engineers selecting PG grades for airfield pavements need to consider what binders are normally used by HMA producers in their area.

PG Grade Slates Within State Highway Departments

The PG grade selection system is based on the temperatures of the area where the pavement is to be constructed, as described in the previous section. Although the potential number of different PG grades in many states is quite large, for practical reasons, the number of grades actually specified by most state agencies is limited. This simplified the grade selection process and makes producing the required PG grades easier for the refiner. It is important when specifying PG grades for airfield pavements to keep in mind that only certain binder grades will be available locally. Although it might be able to procure PG grades not normally specified in a given location, this will tend to increase the cost of the HMA and might also result in scheduling problems. It is therefore suggested that specifications for PG grade selection for airfield pavements should include a list of commonly produced PG grades in each state and Canadian province. This list should be updated on an annual basis.

CURRENT BINDER GRADE SELECTION PROCEDURES FOR AIRFIELD PAVEMENTS

Consistent with the industry, binder selection for airports has gradually evolved from penetration grading to viscosity grading systems. Prior to the adoption of the PG system, most airport pavements constructed before 2000 consisted of AC-10 binder binders in colder regions, AC-20 for the majority of the United States, and AC-30, and in some instances AC-40, for hot climates. The section below briefly discussed several current standards for selecting binder grades for airfield pavements.

Current Standards and Engineering Briefs

Primary FAA guidance on binder selection is contained in Item P-401 and Item P-403 specifications. The P-401 specification is intended for flexible pavement surface course (i.e., top 4 to 5 inches) and the P-403 specification is primarily intended for bituminous base and leveling courses. Both specifications are contained in FAA Advisory Circular 150/5370-10A, "Standards for Specifying Construction of Airports", dated April 2005. Although the specifications permit the use of PG, penetration and viscosity grades, a "Note to the Engineer" states that PG grades should be specified wherever available. However, virtually all hot mix asphalt pavements constructed today utilize PG binders, including California, which recently adopted the PG system.

FAA guidance on binder selection does include suggested restrictions on the "cold" side of the binder grading and suggests guidance for applying "grade bumps." This standard suggests that low-temperature PG grades above XX-22 (for example, a PG 70-16) should not be used, unless the engineer has successful experience with them. High temperature grade adjustments are based on tire pressure, design aircraft gross weight, and location of the pavement within the facility. Tire pressures below 100 lb/in^2 require no bumping; for tire pressures from 100 to 200 lb/in^2, the high-temperature grade should be increased one level; for tire pressures greater than 200 lb/in^2, the grade should be increased two levels. Grade adjustments for aircraft weight and pavement location are given in Table 1, taken directly from the specification.

Therefore, except for exceptional conditions, the FAA suggest the use of only three binder grades in the national standards, PG 64-22, PG 70-22, or PG 76-22, with binder selection consistent with local practice based on the caveats discussed. As discussed below, this can be modified on a regional basis.

Other guidance is provided in FAA Engineering Brief No. 59, "Item P-401 Plant Mix Bituminous Pavements (Superpave)", dated December 2001; Engineering Brief No. 51, "Polymer-modified Asphalt", dated November 1994; Engineering Brief No. 45, "Polyethylene Modified Asphalt Cement", dated February 1990; and Engineering Brief No.39, "Styrene-Butadiene Rubber Latex Modified Asphalt, dated March 1987. Of these, Engineering Brief No 59 is perhaps more widely applied than the other; however, most hot mix airport pavements are produced using Marshall, rather than Superpave, mixes. In any case, the binder selection guidance contained in Engineering Brief No. 59 is essentially the same as that contained in the P-401 and P-403 specifications.

There are also regional modifications to the national P-401/P-403 standards, which contain guidance applicable to a particular FAA Region. The most comprehensive of these is the Northwest Mountain Region's (ANW) modification concerning binder selection. The ANW modification recommends using as a base high-temperature PG grade that which the local highway agency uses for roadways with design traffic levels over 10 million ESALs. This should be adjusted upward one grade for design aircraft weight between 60,000 and 100,000 lb., and two grades if the design aircraft exceeds 100,000 lb. This document includes a table of suggested based PG grades if information is unavailable from the local state highway agency.

Table 1.
PG Grade Adjustments for Aircraft Weight and Pavement Location, as Given in FAA Circular 150/5370-10A.

Aircraft Gross Weight (pounds)	High Temperature Adjustment to Base Binder Grade for Pavement Type:	
	Runway	Taxiway/Apron
Less than 12,500	--	--
Less than 60,000	--	1
Less than 100,000	--	1
Greater than 100,000	1	2

NOTES:

1. *PG grades above a –22 on the low end (e.g. 64–16) are not recommended. Limited experience has shown this to be a poor performer.*
2. *PG grades below a 64 on the high end (e.g. 58-22) are not recommended. These binders often provide tender tendencies.*
3. *PG grades above a 76 on the high end (e.g. 82-22) are not recommended. These binders are very stiff and difficult to work and compact.*

APPROACH TO SELECTING HIGH-TEMPERATURE PG GRADES FOR AIRFIELD PAVEMENTS

High temperature grading in the PG system is designed to provide a binder with an appropriate degree of resistance to permanent deformation, so that pavements made using a properly graded binder will resist rutting but not be excessively stiff. Adapting this part of the PG system to use for airfield pavements is much more complicated than the low-temperature grading adjustment, because the impact of higher wheel loads and tire pressures on rutting is probably much more significant than their effects on thermal cracking.

There are several aspects to high-temperature grading in the PG system that must be modified for use of the system for airfield pavements. Probably the most important is the higher stress levels exerted on the pavement surface by many aircraft. The stress at and near the pavement surface will be proportional to the tire inflation pressure—about 90 to 120 lb/in^2 for commercial trucks, but ranging from less than 40 lb/in^2 for some general aviation aircraft to over 300 lb/in^2 for the F15C fighter. The increased tire pressures for large aircraft will cause a significant increase in rutting compared to a similar number of passes by commercial trucks. Another important difference in rutting in airfields compared to highway pavements is that the amount that aircraft wander across runways and taxiways is much greater than the amount trucks wander across a highway. In fact, wander is often ignored in highway pavement design. Furthermore, the gear configurations on aircraft vary widely and are not directly comparable to the typical number and types of axles on a commercial truck. Therefore, an effective system for selecting PG grades for airfield pavements must account for differences between trucks and aircraft in tire pressure, wander and wheel/gear configuration. Another potential difference between airfield and trucks is the decrease in stress with depth in the pavement. Because of the greater wheel size for large aircraft compared to trucks, it should be expected that the stress under large aircraft tires will not decrease as quickly as under truck tires. This suggests that some care is needed when reducing PG grades with increased depth within a pavement. However, in highway pavement design, grades are reduced according to changes in temperature within the pavement, and not according to changes in stress under loading. Therefore, no modification should be needed in this aspect of PG grading, although reductions of more than one grade in HMA intended for airfield base courses should be avoided, as there is some evidence that large differences in binder stiffness between surface courses and base/binder courses can contribute to surface cracking in some pavements (*5*).

Determining Equivalent Highway ESALs

The general approach suggested for selecting high-temperature PG grades for airfield pavements revolves around the concept of equivalent highways ESALs. An ESAL is an equivalent single axle load; this is the number of standard, 18,000-lb axles loads required to damage a pavement the same amount as a given blend of traffic. The concept of design ESALs is used throughout the Superpave system of pavement design and analysis, including in binder selection. In PG grades selection, the design life of the pavement is always assumed to be 20 years. Consider the following example. A highway traffic lane carries only trucks, each with four axles of approximately 18,000 lbs, and if the total yearly traffic is 100,000 vehicles. Then the design ESALs for this lane would be 4 x 100,000 x 20 = 8,000,000 ESALs, or 8.0 MESALs. An EHE is simply the number of highway ESALs that will cause damage equivalent to the given mix of aircraft traffic on an airfield pavement. Once the design EHEs for a given airfield pavement are known, along with the aircraft speed, the required binder PG grade can be selected using essentially the same procedure used for highway pavements. The EHEs for rutting for an airfield pavement can be calculated using the following equation (*6*):

$$EHEs = \sum_{i=1}^{m}\left[(TP_i)\left(\frac{PDR_i}{PCR_i}\right)(D_i)\right](Y)\left(1+\frac{R}{100}\right)^{0.5Y} \quad (1)$$

where:

TP_i	=	tire pressure factor for the ith aircraft group
PDR_i	=	pass to departure ratio for the ith aircraft group
	=	1 for parallel taxiways
	=	2 for central taxiways
	=	2 for runways with parallel taxiways
	=	3 for runways with central taxiways
PCR_i	=	pass to coverage ratio for the ith aircraft group
D_i	=	initial annual departures for the ith aircraft group
tire)		
Y	=	design life, in years (assumed to be 20 unless otherwise noted)
R	=	annual growth rate in traffic, % (assumed to be 2 % in this analysis)

In airfield pavement design, the PCR refers to the value for taxiways and runway ends leading to taxiways. The value for the central portion of runways will be larger, because the wander at these locations is greater. Unfortunately, specific PCR values for the central portion of runways (hereafter referred to simply as "runways") have not been published. Research has however suggested that the amount of wander in this location, as expressed in the standard deviation of aircraft position, is on average twice the value for taxiways (*7*). The PCR for runways (PCR/R) can then be estimated using the following relationship (*6*):

$$\text{PCR/R} = 1+[2 \times (\text{PCR} - 1)] \tag{2}$$

Determination of the tire pressure factor is somewhat complicated, and is explained in detail below, along with procedures for determining the grade adjustments for speed and depth.

DEVELOPMENT OF TIRE PRESSURE FACTOR

The stress levels near the surface of a pavement have a very strong effect on rutting—as the stress level increases, the rutting increases. Furthermore, this effect is not necessarily linear, since the response of asphalt concrete under high stress levels at elevated temperatures is highly non-linear. As a first estimate, the stresses near the surface of a pavement are proportional to the applied stress—which is equal to the tire inflation pressure. Because tire pressures for aircraft are often much higher than for commercial trucks, accounting for the effect of increased tire pressure on rutting is a critical aspect of selecting binder PG grades for airfield pavements.

During Phase I of Project 04-02, four different models were identified that relate stress level to rutting in HMA pavements:

1. The model used in the Mechanistic Empirical Design Guide (MEDG) developed during NCHRP Project 1-37 (*4*)
2. The rutting/resistivity model developed during NCHRP Projects 9-25 and 9-31 (*8, 9*)
3. The rutting model developed by Kaloush and Witczak early during NCHRP Project 1-37 (*10*)
4. The model developed in the early 1990's by Leahy and Witczak (*11*)

The first two of these have been calibrated to a range of field data and appear reasonably accurate, and predict a similar relationship between tire pressure and rutting. Kaloush and Witczak's model is based on laboratory data alone, and in fact is a precursor to the MEDG model; therefore, it should not be considered for use in developing the tire pressure factor. Leahy and Witczak's model is also based on laboratory data alone. Furthermore, this model predicts much less sensitivity to stress level than the MEDG and rutting/resistivity models. Therefore, it does not appear to be applicable to field rutting and the determination of the tire pressure factor for airfield pavements. Of the first two models, it was decided to use the first—the MEDG model—to maintain consistency with what will likely be standard practice in highway pavement design in the future, and also for consistency with LTPPBind 3.1, which is based on the MEDG model.

Stress Dependency According to the MEDG Model

In the latest published version of the MEDG, the following equation is used to model permanent deformation in flexible pavements (*4*):

$$\frac{\varepsilon_p}{\varepsilon_r} = k_1 \times 10^{-3.4488} T^{1.5606} N^{0.479244} \tag{3}$$

Where

k_1	=	a factor that depends upon total thickness of HMA layers and depth within the pavement of the point considered
ε_p	=	accumulated plastic strain at N repetitions in the given HMA layer, in/in
ε_r	=	resilient strain in the HMA mixture under the given conditions, in/in
T	=	temperature, °F

In the interest of brevity, the derivation is not shown in this paper, but it can be shown that Equation 3 and related mathematical relationships given in the MEDG lead to a simple relationship between the tire pressure factor TP and tire pressure:

$$TP = \left(\frac{p}{120}\right)^{2.09} \tag{4}$$

Since resilient strain in this case is determined using linear elastic analysis, it will be proportional to the applied stress (tire pressure p), all else being equal. Therefore, the MEDG predicts that the number of loads required to reach a given level of plastic strain will be proportional to $p^{2.09}$. The value of 120 in the denominator of Equation 4 represents the typical heavy truck tire inflation pressure of 120 lb/in^2, as assumed in the development of the MEDG.

Verification of the Relationship between Rutting and Applied Stress

Because the relationship between tire pressure, surface stress and rutting is so essential go high-temperature grade selection for airfield pavements, it was felt an independent confirmation of the relationship in Equation 4 was needed. For this purpose, a large data set of results from a repeated load test was analyzed to determine the relationship between rut resistance and applied stress. The test was performed using the newly developed simple performance tests (SPT) developed during NCHRP Projects 9-19 and 9-29 (*12, 13*). In the SPT repeated load test, a pulse load is applied to an HMA cylinder once every second, until failure occurs, failure being defined as the point at which the creep rate begins to increase with continued loading. This is called the flow point, and the number of cycles to the flow point is called the flow number (*12, 13*). The data set was published recently in NCHRP Report 547 (*14*).

The data in this set includes results on HMA samples taken from four sections of the MN/Road project, seven sections of the WesTrack project, and from three of four test sections constructed on I-80 east of Reno, Nevada, in 1998. Data from the NCAT test track was reviewed, but did contain enough test results at different stress levels to be of value. The test temperatures varied from 90 to 130°F. All of the test data were from unconfined tests; although the results of many confined tests were included in the database, none of those reviewed to date included enough variation in applied deviatoric stress level to be useful in this analysis. The deviatoric stress—meaning the applied uniaxial stress—varied from 5 to 406 lb/in^2. The initial modulus of the specimens tested, ranged form about 35,000 to nearly 1,200,000 lb/in^2. The flow number for the tests analyzed to date ranged from 31 to over 112,000. However, because it was felt that tests giving very low and very high flow numbers were potentially suspect, tests with flow numbers below 100 or over 30,000 were eliminated from the analysis. Overall, 100 observations were included in the analysis completed to date.

After compiling the data for the tests and performing some initial simple graphical analyses, the data was analyzed using multiple regression. The objective in this analysis was to determine the sensitivity of the flow number to changes in stress level, the primary assumption being that the relationship between allowable load repetitions in a runway pavement and stress level will be similar to the relationship between flow number and stress level in the laboratory. The statistical analysis indicated that the relationship between flow number, modulus and applied stress can be expressed using the following relationship:

$$FN = A\left|E*\right|^{B}\sigma_{DEV}^{C\log\left|E*\right|} \tag{5}$$

Where A, B and C are constants. According to the results of the statistical analysis, the value of constants A and C vary from mix to mix, while the value of B is constant at 2.937. The values of the constants A and C for the 14 mixtures were statistically similar for most mixtures, but statistically significant differences were observed for a few of the WesTrack mixtures. The r-squared value for the model was 78.7 %, indicating that over three-quarters of the variability in the data set was explained by the model represented by Equation 5.

Figure 1 is a plot of the stress exponent ($C \log|E*|$) in Equation 5 for the various mixtures included in the analysis. Note that most of the values for the stress exponent fall between –1.0 and –2.5, with the exception of the value for WesTrack Section 11, which is so far away from the other data points that it is suspect as an outlier. All of the values that fall below -2.00 are for modulus values above 500,000 lb/in^2, where rutting should not normally be a problem. Therefore, this analysis confirms the relationship between rutting and stress/tire pressure inherent in the MEDG and expressed previously in Equation 4. For the sake of simplicity, it is suggested that the stress exponent for calculating the tire press factor (TP) in calculating EHEs be conservatively assumed to be 2.0. In other words, the number of damage-based equivalent loads in an HMA pavement is proportional to the square of the tire pressure. For example, an aircraft tire inflated to 240 lb/in^2 will do four times as much damage as a typical truck tire inflated to 120 lb/in^2. Similarly, a tire inflated only to 60 lb/in^2 will do one-fourth the damage of a typical truck tire. The suggested method for estimating the affects of stress on HMA rutting addresses the full range of tire pressures occurring on commercial, general aviation and military aircraft.

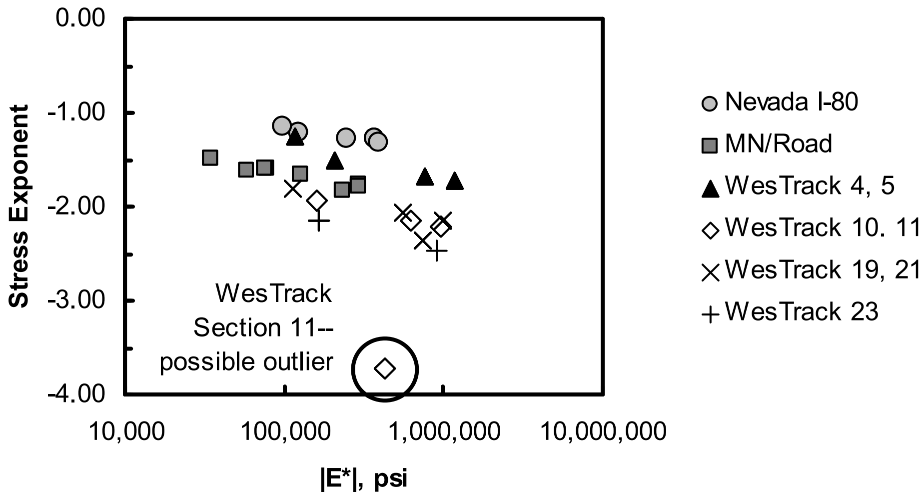

Figure 1. Stress Exponent for Equation 5 as a Function of Mixture Modulus for Several Test Roads.

GRADE ADJUSTMENTS FOR TRAFFIC LEVEL AND SPEED

The new version of LTPPBind 3.1 includes rational, damage based traffic level and speed adjustments (*2*). The intent of this procedure is to rely on much as possible on the LTPPBind 3.1 software, which provides PG grade adjustments for traffic. Therefore, it is not necessary to develop such adjustments for aircraft, as long as the correction to EHEs is made prior to using LTPPBind. Unfortunately, a similar approach cannot be used for grade adjustments due to traffic speed. LTPPBind 3.1 only provides adjustments for fast and slow traffic, and the precise speeds for which these adjustments apply are not clear, although it appears to be about 45 mph for “fast” speed and 25 mph for “slow” speed. Therefore, another approach is needed.

The problem of adjusting high-temperature PG grade for differences is speed is equivalent to determining the decrease in temperature necessary to offset the modulus decrease resulting from a given decrease in loading rate for a binder. This relationship was determined for seven different binders, ranging from a PG 58-28 to a PG 76-22; two of the binders were polymer modified. The results are summarized in Table 2. The temperature adjustments associated with different reductions in aircraft (or vehicle speed) fall into a relatively narrow range. The adjustment for 25 mph (“slow”) speed using this approach is essentially identical to that contained in LTPPBind 3.1; it is suggested that the adjustment as provided by this program be used for “slow” traffic, corresponding to taxiway traffic with no stacking. However, as mentioned above, adjustments for slower speeds are not included in LTPPBind 3.1. Based upon the range in adjustments for the different binders, it is suggested that for taxiways with some stacking, the high-temperature PG grade should be increased by 6°C, or one grade; for taxiways with frequent stacking, the adjustment should be 12°C, corresponding to two grades. It should be pointed out that the adjustments listed in Table 2 are in general consistent with current practice. For example, the latest version of the *Unified Facilities Guide Specification, Section 02749: Hot-Mix Asphalt (HMA) for Airfields* (UFGS-02749) suggests that rutting is in general not a problem on airfield runways. However, in cases where frequent stacking of aircraft occurs (or if there is a history of rutting at the facility), UFGS-02749 recommends increasing the high-temperature binder grade one or two grades (6 or 12°C) for surface course mixes on the taxiways and runway ends. An increase of one grade is suggested when tire pressures are between 100 and 200 lb/in^2, a two grade adjustment for tire pressures over 200 lb/in^2 and for Navy airfields. As discussed below, most airfield pavements will not require any grade adjustment for design traffic level (EHEs), so the one- to two-grade adjustment given in UFGS-02749 is consistent with the suggested grade adjustments given in Table 2.

Table 2.
Estimated Damage-Based Grade Adjustments for Speed.

Aircraft Speed Classification	**Aircraft Speed** *mph*	*Observed Grade Adjustment for Seven Binders* **Minimum** *°C*	**Maximum** *°C*	**Average** *°C*	**Recommended Grade Adjustment** *°C*
Runways	≥ 45	0	0	0	0
Taxiways with no stacking	25	2	3	2	As given in LTPPBind 3.1 (“slow traffic”)
Taxiways with some stacking	12	5	6	5	+6
Taxiways with frequent stacking	3	10	13	11	+12

PG GRADE SELECTION FOR TYPICAL AIRCRAFT MIXES

To determine the overall relationship between aircraft loading, tire pressure, aircraft wander and high-temperature PG grade, traffic mixes from eight runways were analyzed. The data used was as published in a recent study on airfield pavement design (*15*). In the interest of brevity, details of the aircraft type, characteristics and departures are not presented here. The airfields represented include Sarasota-Bradenton, Dulles, Memphis, Charlotte-Douglas, Philadelphia and JFK. The annual departures range from 3,600 to over 350,000. The results suggest a good relationship between annual departures and EHEs as calculated using Equation 1. Figure 2 is a plot of EHEs calculated using Equation 1 as a function of annual departures multiplied by $(p/120)^2$, where p is tire pressure for the design aircraft on each runway—this accounts for differences in typical tire pressure among the eight runways.

Figure 2 represents the specific case of parallel taxiways; there are three other situations that need to be addressed: runways connected to parallel taxiways, central taxiways and runways connected to central taxiways. The equations relating EHEs to annual departures for each case are as follows:

$$\text{EHEs (taxiway/parallel)} = 8.36 \times (p/120)^2 \times \text{annual departures} \tag{6}$$

$$\text{EHEs (runway/parallel taxiway)} = 10.4 \times (p/120)^2 \times \text{annual departures} \tag{7}$$

$$\text{EHEs (taxiway/central)} = 20.8 \times (p/120)^2 \times \text{annual departures} \tag{8}$$

$$\text{EHEs (runway/central taxiway)} = 15.6 \times (p/120)^2 \times \text{annual departures} \tag{9}$$

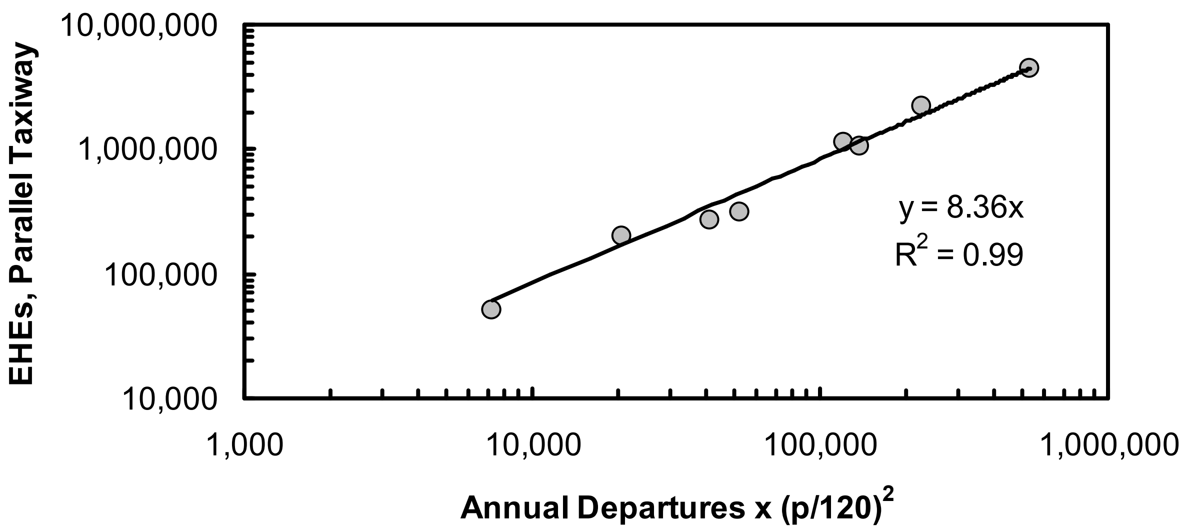

Figure 2. Relationship between EHEs and Annual Departures for Eight Runways.

To simplify calculations of EHEs, it is suggested that Equation 7 be used to calculate EHEs for both taxiways and runways with a parallel taxiway configuration. This results in a somewhat more conservative grade selection for taxiway, equivalent to a slightly slower assumed speed. For the central taxiway configuration, Equation 8 should be used for both runways and taxiways. This results in a somewhat more conservative approach for runways. However, in a central taxiway configuration, aircraft will be taxiing on the runway to and from the central taxiway, and the aircraft speed during this pass will be significantly slower than during landing and takeoff operations. Therefore, the use of Equation 8 for both runways and taxiways is reasonable. It should also be noted that central taxiways are almost always used on small general aviation airfields, where high-temperature binder grade adjustments will generally not be needed. That is, applying Equation 8 to traffic mixes for the sort of airfields using central taxiways will generally result in EHEs that do not reach traffic levels requiring high-temperature grade adjustments. In fact, since LTPPBind 3.1 does not increase the high-temperature PG grade until the traffic level exceeds 3 million ESALs, and as shown in Figure 2 the EHEs for most airfield pavements does not exceed this level, HMA for most taxiways and runways will not require grade adjustments for traffic—only for aircraft stacking.

RECOMMENDATIONS

1. The base high-temperature PG grade should be determined using LTPPBind 3.1, for a surface layer (depth of layer surface = 0 mm), using a reliability of 98 %.

2. For a parallel taxiway configuration, the EHEs for both taxiways and runways are calculated using Equation 7:

$$\text{EHEs} = 10.4 \times (\text{design tire pressure in lb/in}^2 / 120)^2 \times \text{annual departures} \tag{7}$$

3. For a central taxiway configuration, the EHEs for both taxiways and runways are calculated using the following Equation 8:

$$\text{EHEs} = 20.8 \times (\text{design tire pressure in lb/in}^2 / 120)^2 \times \text{annual departures} \tag{8}$$

4. The high-temperature PG grade is then determined using LTPPBind 3.1, using the calculated value for EHEs as the design traffic level. For all runways, no speed adjustment is needed in LTPPBind 3.1 ("fast" traffic condition). For taxiways without stacking, the speed adjustment for "slow" traffic as given in LTPPBind 3.1 should be used. For taxiways with some stacking, the high-temperature PG grade should be increased by 6°C; for taxiways with frequent stacking, the grade should be increased by 12°C. For taxiways subject to frequent stacking of aircraft, polymer modified binders have exhibited good performance, and their use should be preferred to conventional asphalt binders.

5. The resulting PG grade may or may not be available locally on a regular basis. If not, the binder selected should have at least the same high-temperature PG grade determined in step 4. Final guidelines for binder PG grade selection for airfield will include a list of available PG grades for each state.

6. PG grades with low temperature limits above -22 (for example, PG 64-16, PG 70-16), should not be specified for airfield use unless significant local experience indicates that they will exhibit good performance.

7. The high-temperature PG grade may be reduced one level (6°C) for lifts which are entirely 75 mm or more below the pavement surface. No additional grade reductions should be made.

As part of this research, the effect of stress/tire pressure on rutting rate is being confirmed through laboratory testing. Also, the PG grade selection procedure is being evaluated in a number of ways, including an analysis of case studies of existing airfield pavements. An important issue not addressed in this paper because of space limitations is polymer modified binders. Significant evidence exists at this time that polymer modified binders provide significantly greater levels of rut resistance than non-modified binders of an equivalent grade. This effect is being studied, with the objective of at least partially addressing this benefit in the final grade selection procedure. Although not specifically addressed in this paper, low-temperature PG grade selection is also being studied as part of AAPTP project 4-2. At this time, the low-temperature PG grades as given in LTPPBind 3.1 appear to be reasonable for most or all airfield applications. Because work on this project is still continuing, the findings given here should be considered preliminary.

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